ACCURACY OF A TRANSFORMATION METHOD TO ESTIMATE MUSCLE ATTACHMENTS BASED ON THREE BONY LANDMARKS

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INTRODUCTION

In [1], a linear transformation method was presented, which allows the scaling of specimen muscle attachments to a specific subject, using three landmarks of the specimen segment, and the three respective landmarks of the homologous segment of the subject. This transformation method is defined in the following way:

Given two homologous segments, to be referred to as object and image segment, we can use three anatomical landmarks of the origin segment, $\mathbf{a}_1 = (a_{11}, a_{12}, a_{13})$, $\mathbf{a}_2 = (a_{21}, a_{22}, a_{23})$ and $\mathbf{a}_3 = (a_{31}, a_{32}, a_{33})$, and three anatomical landmarks of the image segment, $\mathbf{b}_1 = (b_{11}, b_{12}, b_{13})$, $\mathbf{b}_2 = (b_{21}, b_{22}, b_{23})$ and $\mathbf{b}_3 = (b_{31}, b_{32}, b_{33})$ to compute the scaling linear transformation $T(\mathbf{x}) = BA^{-1}\mathbf{x}$, where $A = [\mathbf{a}_1 \quad \mathbf{a}_2 \quad \mathbf{a}_3]$ and $B = [\mathbf{b}_1 \quad \mathbf{b}_2 \quad \mathbf{b}_3]$. This method was tested with a dataset of landmarks and muscular attachment lines of seven cadavers, provided by the Dutch shoulder group webpage (http://www.fbw.vu.nl/research/Lijn_A4/shoulder/overview.htm) [2]. The error obtained, which in this work we will refer to as global error, was 7 mm for scapula and 11 mm for humerus. We identify two contributors to global error: inter-subject variability, and mathematical error resulting from the properties of the scaling transformation.

METHODS

If we had two segments such that the second were a translation, followed by a rotation, of the first, applied the scaling linear transformation to a muscle attachment line of the first segment, and then measured the error as described in [1], then the expected value for this error would be zero, since translation and rotation do not change the relative disposition of the segment's muscle attachment line in relation to its anatomical landmarks. In other words, we would be scaling a segment to itself. Therefore, any error in this operation could only be attributable to the mathematical properties of the transformation. With this in mind, we defined mathematical error by the following procedure:

1 – Effect the translation of segment S_1, corresponding to the points $\mathbf{a}_1$, $\mathbf{a}_2$ and $\mathbf{a}_3$, by the vector $\mathbf{v}$. This will result in segment S_2, represented by the points $\mathbf{b}_1 = \mathbf{a}_1 + \mathbf{v}$, $\mathbf{b}_2 = \mathbf{a}_2 + \mathbf{v}$ and $\mathbf{b}_3 = \mathbf{a}_3 + \mathbf{v}$.

2 – Rotate S_2 around its centroid, $\mathbf{d}$. This results in segment S_3, represented by points $\mathbf{c}_1 = R(\mathbf{a}_1 + \mathbf{v} - \mathbf{d}) + \mathbf{d}$, $\mathbf{c}_2 = R(\mathbf{a}_2 + \mathbf{v} - \mathbf{d}) + \mathbf{d}$ and $\mathbf{c}_3 = R(\mathbf{a}_3 + \mathbf{v} - \mathbf{d}) + \mathbf{d}$, where R is the rotation matrix.

3 – Apply the scaling transformation to $\mathbf{x}$ with S_1 as object segment and S_3 as image segment. This is given by $CA^{-1}\mathbf{x}$, where $C = [\mathbf{a}_1, \mathbf{a}_2, \mathbf{a}_3]$ and $C = [\mathbf{c}_1, \mathbf{c}_2, \mathbf{c}_3]$.

4 – Apply steps 1 and 2 to $\mathbf{x}$. This results in the point $\mathbf{y} = R(\mathbf{x} + \mathbf{v} - \mathbf{d}) + \mathbf{d}$.

5 - Compute the mathematical error vector. This is given by $\vec{\varepsilon} = CA^{-1}\mathbf{x} - \mathbf{y}$. Its norm is the mathematical error, defined as $\varepsilon = \| CA^{-1}\mathbf{x} - \mathbf{y} \|$.

We first considered the effect of translation on ε. To do this, in the above procedure we applied no rotation, that is, the rotation matrix is the identity matrix. In this way we have shown that ε increases with the distance between **x** and the plane P passing by the three landmarks defining the segment. When this distance is zero, we have ε=0. Error also increases with the norm of the translation vector. On the other hand, ε is invariant with the direction of the translation vector. Second, we considered the effect of rotation on ε. To this end, we applied the above procedure with $\mathbf{v}=\mathbf{0}$. We verified that, as in the case of translation, ε increases with the distance between **x** and P. We also verified that, in an axis-angle representation, ε increases with the angle θ of rotation, reaching a maximum at θ=π, and then decreases symmetrically until a full rotation is achieved at θ=2π, when error is again zero. We have also seen that if the axis of rotation coincides with the vector of the centroid, then ε=0.

In order to define a notion of mathematical error associated with an object segment, an image segment and a muscular attachment point, we used the following alignment criterion: two homologous segments are aligned if their centroids coincide, and the respective coordinate systems are coincident. In this way, given two homologous segments, we calculated the translation and rotation that, when applied to the object segment, aligns it with the image segment, and then computed the mathematical error associated with the object segment, this translation and rotation, and the object segment muscular attachment point in the dataset.

RESULTS AND DISCUSSION

In order to test the above notion of mathematical error the dataset in [2] was used. We then used the same procedure described in [1], obtaining mean values of ε of 2 mm for scapula and 3 mm for humerus. The difference between global error and ε describes anatomical variability, which is 5 mm for scapula and 8 mm for humerus.

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REFERENCES

1. Matias, R. et al. *Journal of Biomechanics* **42(3)**: 331-335, 2009.
2. Dutch Shoulder Group 2003, viewed 5 May, 2008